

PALEOENVIRONMENTS, CLASSIFICATION AND DIAGENETIC ASPECTS OF IRONSTONES IN THE MESOZOIC SEDIMENTS OF EL MAGHARA AREA, NORTH SINAI, EGYPT

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ملخص

تحتوى صخور الميزوزوى بمنطقة جبل المغارة بشمال سيناء على تسعة وعشرين طبقة من الاحجار الحديدية المختلفة حيث قسمت إلى الأنواع الآتية :-

- (١) الأحجار الحديدية العقيدية
- (٢) الأحجار الحديدية الجسيمية (الكثيفة)
- (٣) الأحجار الحديدية الطينية
- (٤) الأحجار الحديدية الطباقية
- (٥) الأحجار الحديدية رقيقة التطبيق
- (٦) الأحجار الحديدية الأوليتية (السريية)

وقد تم دراسة التركيب المعدنى لهذه الأنواع وكذلك نوقشت البيئات الترسيبية القديمة التى تكونت بها من خلال دراسة علاقة هذه الرواسب الحديدية مع الصخور المعاقبة معها . وكذلك تم استنتاج الظروف الفيزيو كيميائية المصاحبة لتكوين المعادن الحديدية المختلفة خلال فترة الترسيب وعمليات ما بعد الترسيب .

ABSTRACT

The Jurassic and Lower Cretaceous sediments of El Maghara area, North Sinai, contain up to twenty nine ironstone beds . These ironstones are intimately associated with a transitional environment of alternating paralic and shallow marine platform sediments, comprising marginal facies of the epicontinental Tethyan sea . They form marker horizons separating the enclosing sediments into different megacycles and contain 17 to 42% iron . The ironstones are classified into the following types : 1) concretionary banded ironstone ; 2) massive goethitic and massive siderite-bearing ironstones ; 3) clayey ironstone ;

4) banded ironstone ; 5) laminated ironstone and 6) oolitic ironstone . The oolitic ironstone include friable and indurated types, the latter with quartz rich and quartz poor varieties . Goethite, pyrite, siderite, chamosite, glauconite and hematite are the main mineral constituents of the ironstones. The concretionary banded ironstones represent lateritic crusts overlying mottled mudstone or ferruginous shales, suggesting an interruption in the cyclic deposition of deltaic sediments . The composition, fabrics and oxidation of the iron minerals of the banded, laminated and massive ironstones indicate alternating reducing and oxidation conditions during the depositional and early diagenetic stages of fluvial successions. The oolitic ironstones suggest deposition in shallow shelf lagoonal and mixed intertidal to shoal environments, with modification during the early diagenetic stages, under oxidation conditions .

INTRODUCTION AND GEOLOGICAL SETTING

The aim of this paper is to reach a better understanding of the nature of different ironstone deposits in the Jurassic and Lower Cretaceous sediments of Gebel El Maghara area, North Sinai (Fig. 1) . These ironstones form marker beds intercalated within the cyclic Jurassic and Lower Cretaceous sediments . They have been studied systematically both in the field and microscopically, using oriented thin and polished sections .

The geology of El Maghara area (Fig. 1) has been intensively investigated by many researchers e.g., Hume et al. (1921) ; Farag (1942,1947,1959) ; Barakat (1956) ; Said and Barakat (1958) ; Al Far (1966) ; Goldberg et al. (1971) , Frankel (1975) and Jenkins et al. (1982) . The area, being part of the mobile region of Northern Sinai, was subjected to compressional forces which gave rise to folded and dome-like structures, as well as epi-anticlinal faults. These tectonic features belong to the surface and subsurface folds of Northern Sinai and Negev which pertain to the "Syrian Arc System", generated as a result of the differential north-ward movement of the central (the Sinai and Arabian subplates) and the northwest African Plates, since Late Paleozoic (Neev, 1975, 1977) The area is covered mainly by sedimentary rocks of Jurassic and Cretaceous ages. The Jurassic rocks are known from the group of high hills of Gebel El Maghara and form the most complete and thickest Jurassic series in Egypt . The Cretaceous sediments crop out to the east and southeast of the domal Jurassic rocks at Gebel Manzour and Gebel Maaza. NW-SE and NE-SW trending faults brought the Jurassic sediments against the Cretaceous rocks along Wadi El Muzaira and Wadi Mashabbah .

The Jurassic successions illustrate, the transitional zone between outer

cycles, reflecting deposition on fluctuating platform, alternating between fluvial and shallow marine conditions along the southern margin of the Tethys, south of the hinge-line of Goldberg and Friedman (1974). The Jurassic section includes six successive formations (Al Far, 1966). From oldest to youngest these are : Mashabbah (Late Triassic ? - Liassic), Rajabiah (Late Triassic ? - Liassic), Shusha (Late Liassic), Bir El Maghara (Late Liassic-Late Bajocian), Safa (Bathonian) and Masajid (Bathonian - Kimmeridgian). The fluviomarine paralic sediments are represented by the Mashabbah, Shusha and Safa formations. Economic coal seams, up to 1m thick, are widespread in the unexposed lower level of the Shusha Formation. The main marine transgressions are displayed by platform carbonates of the Rajabiah, Bir El Maghara and Masajid formations. The latter includes oolitic ironstones. The present field observations denote that occasional uplifting and subaerial erosions took place during the Jurassic. This is manifested by the development of two distinct fossilized paleokarst unconformities. The first one is inferred by the occurrence of solution in cavities and intra-karstic sediments in the upper part of Bir El Maghara Formation, directly underlying the lower part of the Safa Formation. The second paleokarst surface occurs on the top of the Safa Formation and is dominated by small scale solution cavities encrusted by thin veneer of silcrete. Immediately overlying this surface, the transgressive carbonate facies of the Masajid Formation. These paleokarst surfaces form persistent markers which can be traced throughout the whole area of Gebel El Maghara. Further to the south, in Southern Sinai, there are no signs of marine Jurassic and the equivalent facies, the lower and middle horizons of the Malha Formation of Abdallah and Adindani (1963), are almost entirely continental as represented by fluvial sandstones intercalated with continental red beds and paleosols (El Barkooky, 1986 and Barakat et al., 1986).

The Cretaceous succession (Aptian-Albian) of Gebel Manzour includes in its lower and middle parts an alternation of clastic sediments, oolitic limestones and ironstones of intertidal to shoal environments. Above these sediments rest stylolitic dolomites and limestones. In central Sinai and Gulf of Suez, the equivalent sediments, the upper part of the Malha Formation, are essentially of continental origin, consisting of kaolinitic sandstones with occasional paleosol intercalations (El Barkooky, 1986 and Barakat et al., 1986). Both types of facies were overlapped by major marine Cenomanian transgression, where the Raha or Galala formations are well developed.

This overall view points out that the sedimentary successions of El Maghara area represent the marginal facies of the epi- Tethyan sea during Jurassic- Early Cretaceous, bounded to the south and southeast by emergent regions with continental and lateritic deposits and to the north by the active hinge-line and the Tethyan Sea. They also reflect the tectonically active (emersion, erosional) habitat of the basin during that time.

CYCLIC SEDIMENTATION AND STRATIGRAPHIC DISTRIBUTION OF THE IRONSTONES

The Jurassic and Lower Cretaceous sediments contain as many as twenty nine ironstone beds distributed throughout the studied sections. The ironstone layers form marker horizons, separating the intervening sediments into different megacycles. Each megacycle consists of successive rhythmic alternations of different lithologic units.

The fluviomarine Shusha Formation (Fig. 2) consists within its lower part of repeated coarsening-upward successions which can be assigned to

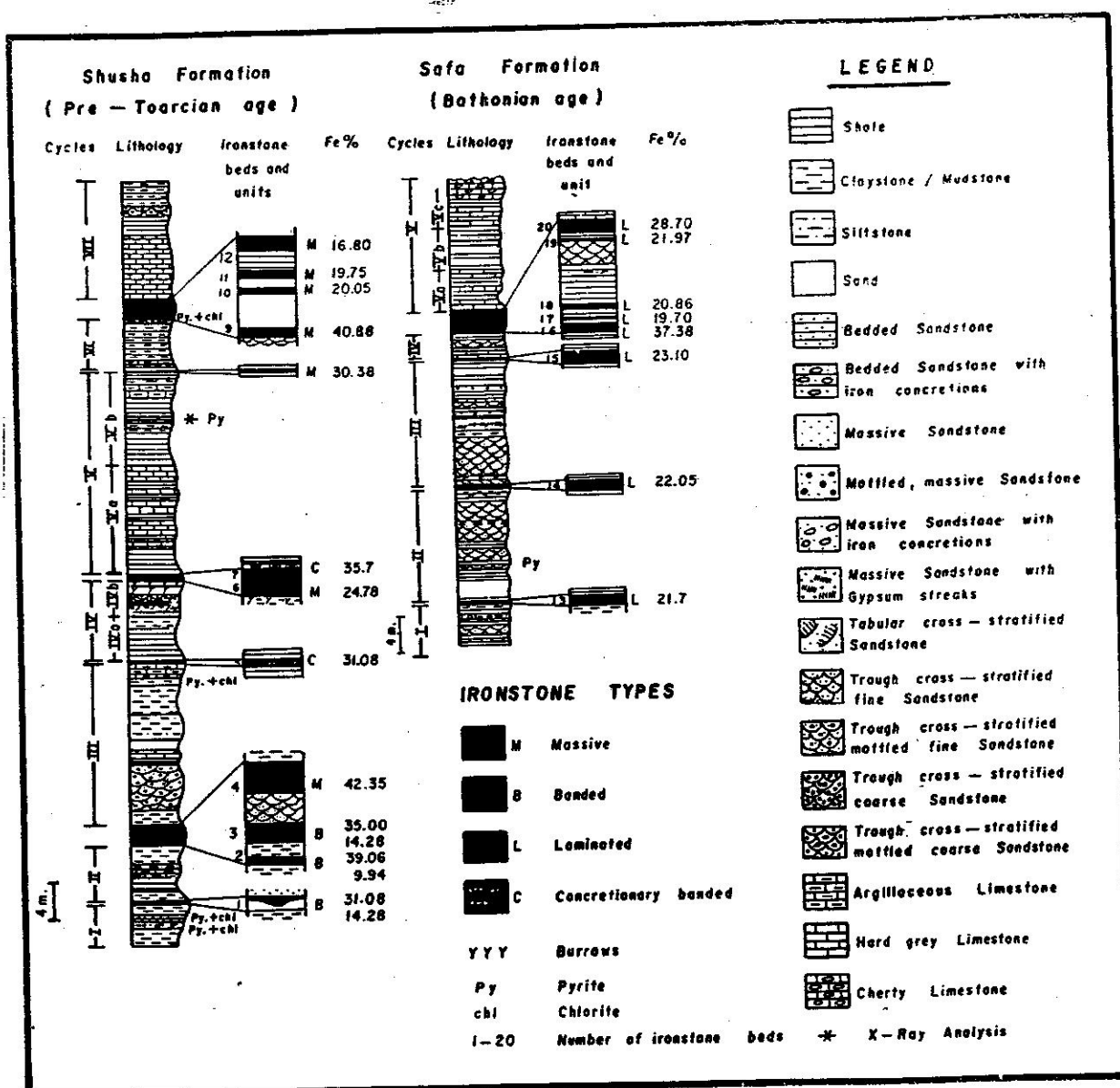


Fig. 2 : Lithostratigraphic columns of the Shusha and Safa formations.

delta cycle, generated by gradual progradation of delta into shallow marine water. Each sequence begins with mudstone, fissile shale and ironstone, passing gradually into thin laminated siltstone and cross-bedded sandstone. Ripple bedding, current ripples, burrowings and small scale graded bedding are common in more silty layers. Carbonaceous materials and pyritized plant remains are frequently distributed throughout these sequences, usually disseminated along the horizontal and cross bedding planes or occur as discontinuous thin laminae confined to ripple troughs. Marine fossils are also present, generally restricted within some shale layers. These deltaic sequences are terminated by ironstone bed which succeeded by transgressive succession of alternating limestone and shale. The upper part of the section is built up of alternating sequences of deltaic and marine sediments with ironstone bands. The ironstones divide these sediments into seven large scale stratigraphic cycles. They occur as separate beds or form banded, small scale cyclic units alternating with clastic sediments. The ironstone bands may be massive, laminated or consist of coalescent concretions.

The Safa Formation (Fig. 2) consists within its lower section of repeated fining-upward sequences of simple rhythmic alternations of sandstone and shale, suggesting fluvial succession, resulted from progradation of deltaic tidal flat sediments. The sandstones show tabular and trough cross-bedding, flaser and convolute bedding, load casts and burrowing. Thin laminae of coal, pyritized plant remains and pyrite specks are common. Transgressive marine sequence of simple rhythmites of shale and limestone constitutes the upper part of the section. The rhythmic alternations of the lower deltaic sequences are separated by ironstones into five cycles. These ironstone bands also have a rhythmic laminated character.

The marine Masajid Formation is divided into the lower Kehailia Member and the upper Arousiah Member (Fig. 3). The former consists mainly of limestones (bio-oo-pelmicrites, sandy and chamositic in some parts), rhythmically alternated with sandstone and shale, suggesting formation in shallow shelf lagoonal environment in proximity of landmass. The rhythmic alternations of this member are subdivided into three main cycles. The lower two cycles culminate in ironstone caps, whereas the uppermost cycle passes up into thick reefal limestones of the Arousiah Member. The ironstone caps are of rhythmic laminated or oolitic nature.

The lower Cretaceous section of Gebel Manzour consists essentially of mixed clastic and limestone beds of mixed intertidal to shoal environments, followed by sandy dolomitized and stylolitic limestone (Fig. 3). The interlayered limestones are thin to thick bedded, sandy, fossiliferous and mostly oolitic. Petrographically, they are oosparite, bio-oosparite and biosparite, being in parts sandy and argillaceous. These sediments contain marker beds of ironstone facies which separate the section into six distinctive sedimentary cycles, the ironstones contain ferruginous ooids or of clayey nature.

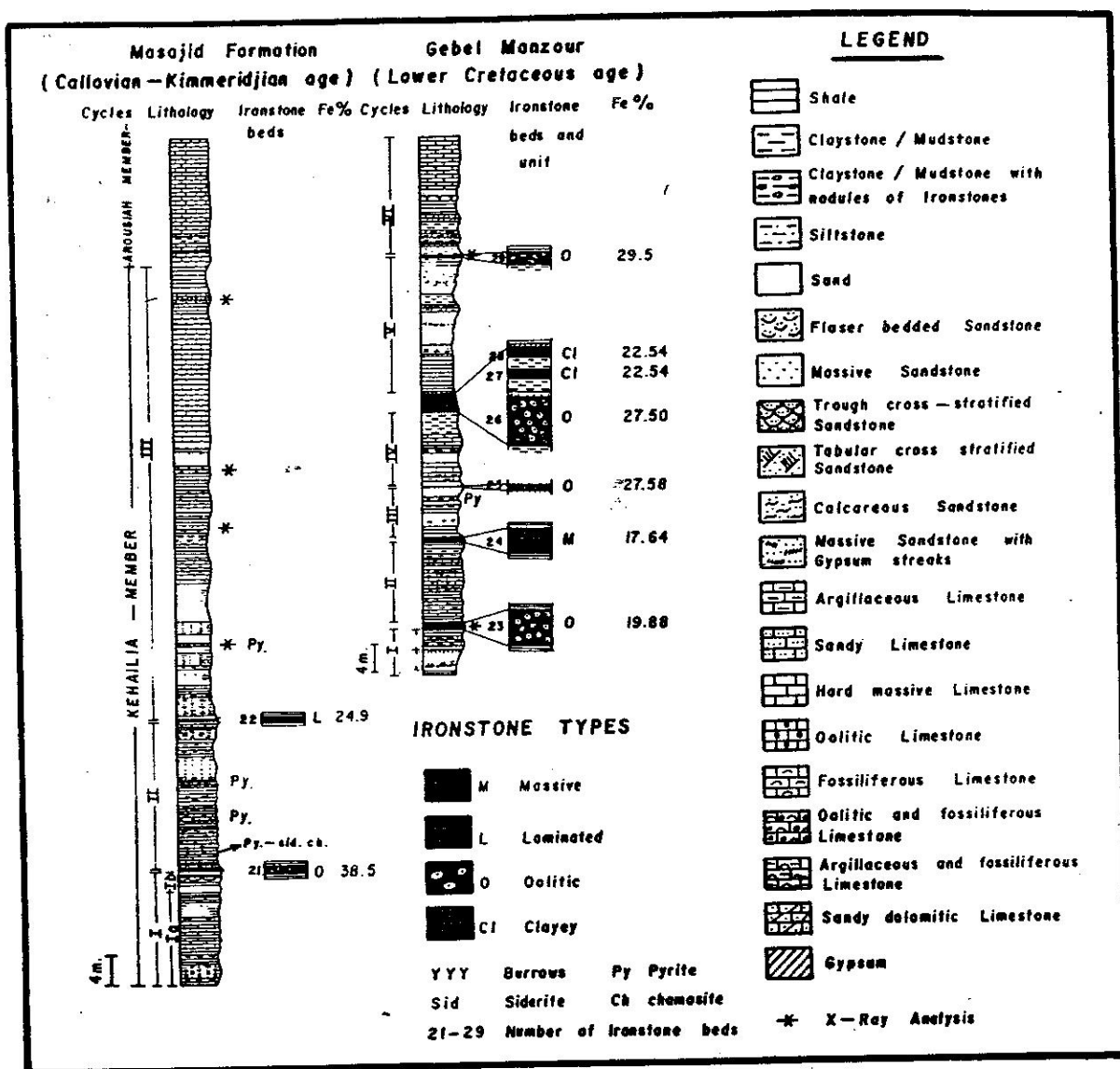


Fig. 3 : Lithostratigraphic columns of the Masajid Formation and the Lower Cretaceous sediments of Gebel Manzour.

MEGASCOPIC AND MICROSCOPIC CHARACTERISTICS OF THE IRONSTONES

The ironstones are classified into six main types according to their geological setting, fabrics, mineral composition and iron content : concretionary banded, massive, clayey, banded, laminated and oolitic. The iron content of these types ranges between 17 to 42% Fe (table 1) .

Concretionary Banded Ironstones

This ironstone type occurs in the middle part of the Shusha Formation. Individual beds include concretions, up to 11 cm in diameter and 35.7% Fe. This type of ironstone is massive ironstone and/or mottled, burrowed and highly

Table (1) : Chemical analysis of different ironstone types.

Type of ironstone	No. of the ironstone bed	Formation	Sample No.	Fe O % 2 3 total	Fe %		
banded ironstone	1	Shusha (Sh)	Sh 14 dark	44.4	31.08		
	2		Sh 14 light	20.4	14.28		
			Sh 27 dark	55.8	39.06		
			Sh 27 light	14.2	9.94		
			Sh 29 dark	50.0	35.00		
	3		Sh 29 light	20.4	14.28		
Laminated ironstone	13	Safa (F)	F 246	31.0	21.70		
	14		F 235	31.5	22.05		
	15		F 210	33.0	23.10		
	16		F 203	53.4	37.38		
	17		F 201	28.15	19.70		
	18		F 199	29.8	20.86		
	19		F 196	31.4	21.97		
	20		F 194	41.0	28.70		
	22	Masajid (F)	F 60	51.8	36.26		
Concretionary banded ironstone	5	Shusha (Sh)	Sh 45	44.4	31.08		
	7		Sh 62	51.0	35.70		
Massive banded ironstone (goethitic)	4	Shusha (Sh)	Sh 33	60.5	42.35		
	6		Sh 61	35.4	24.78		
	8		Sh 90	43.4	30.38		
	9		Sh 96	58.4	40.88		
	10		Sh 98	28.22	19.75		
	11		Sh 98	28.64	20.05		
	12	Sh 100	24.0	16.80			
Massive siderite-bearing glauconitic ironstone	24	Gebel Manzour	46	25.2	17.64		
Clayey ironstone	27	Gebel Manzour	22 a	32.2	22.54		
	28		22 b	31.5	22.05		
litic - ironstones	Friable	25	Gebel	33	39.4	27.58	
		26	Manzour	24	39.29	27.5	
	Indurated	Quartz-rich	29	Gebel Manzour	11	29.2	20.44
			Quartz-poor	23	Gebel Manzour	69	28.4
						24.6	17.22

disintegrated mudstone and shale. The concretions consist mainly of concentric laminae of goethite with or without muddy sediments, silty quartz grains and shell fragments. Smaller concretions or pisolites, up to 2 cm in diameter, consist of very thin concentric laminae of reddish yellow to reddish brown goethite and hematite. Hematite occurs in the central zone of the concretions as fine bladed crystals arranged perpendicular to the growth direction. It is followed by concentric colloform laminae of goethite together with muddy sediments (Fig. 4a). Most concretions were affected by syndimentary microfault structures.

Massive Ironstones

Massive ironstones are recorded in the Shusha Formation and the Lower Cretaceous sediments of Gebel Manzour, where they reach up to 70 cm in thickness. Both goethitic and siderite-bearing glauconitic varieties of massive ironstone are present. The goethitic massive ironstone (up to 42% Fe) is well represented in the Jurassic Shusha Formation, especially in the upper part. It consists mainly of silty quartz grains cemented by goethite together with kaolinite (Fig. 6). A small amount of oxidized spindle-shaped siderite grains ($< 2 \mu$) and minute crystals and framboids of pyrite ($< 4 \mu$) are randomly disseminated in the goethite cement. The siderite-bearing glauconitic massive ironstone (up to 17.6% Fe) is developed in the Lower Cretaceous sediments, forming a continuous yellowish red and massive bed in the middle part of the section. It includes 40% angular quartz grains (silt to sand size), 10% detrital glauconite and 3% fossil debris. These detrital materials are enclosed in a microsparitic calcite cement which includes kaolinite (Fig. 6) and altered siderite (47%). The glauconite pellets, up to 500 μ in size, form rounded or fragmented grains (Fig. 4b). The fossil debris include algae, echinoid spines, foraminifera and pelecypod fragments. The algal fragments show remains of organic structures which are partially lined or completely filled with calcite, forming a bird's eye texture. Siderite forms spindle-shaped crystals, up to 50 μ in size, and is partially to completely altered to goethite and commonly cemented by the microsparite.

Clayey Ironstone

Clayey ironstones form powdery red ochre alternating with green clays in the upper horizon of the Lower Cretaceous succession of Gebel Manzour. The ochre, up to 22.54% Fe, attains a thickness of about 30 cm and consists of earthy goethite and hematite with kaolinite.

Banded Ironstones

These ironstones are present in the Shusha Formation as several banded, red to dark brown layers intercalated with the clastic cyclic successions, especially near the base of the formation. Layers are up to 40 cm and consist of rhythmic alternations of thin, dark, highly ferruginous

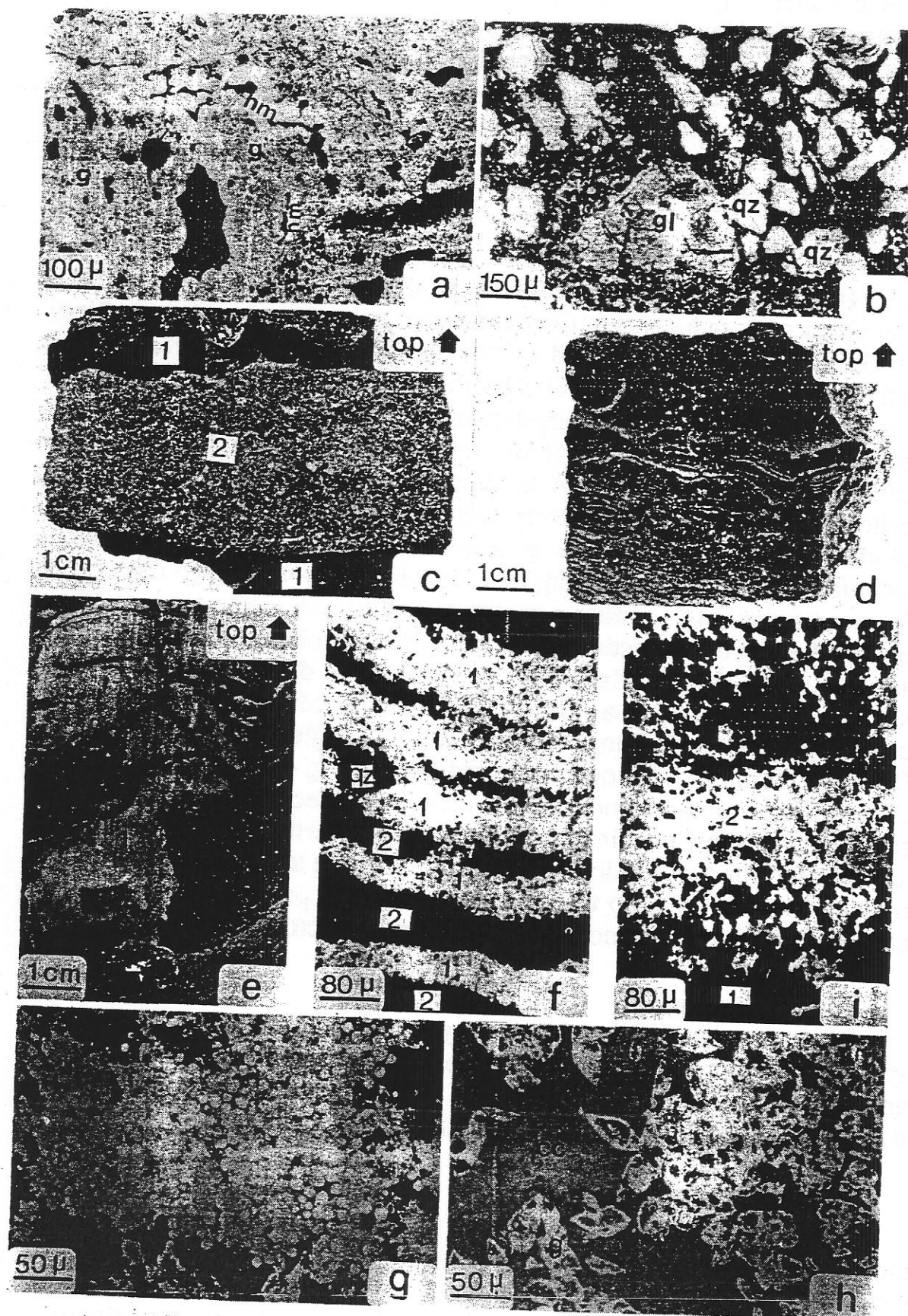


Fig. 4

- a) Polished section of iron concretion consisting of concentric crusts of colloform hematite (hm) and goethite (g), concretionary banded ironstone, Shusha Formation.
- b) Thin section of the siderite bearing glauconitic ironstone, consisting of detrital glauconite (gl) and quartz (qz) cemented by siderite and microsparite, Lower Certaxeous sediments.
- c) A polished slab of the banded ironstones, consisting of highly (1) and less (2) ferruginous bands. Notice, the scour and fill structure on the upper surface of the dark band, Shusha formation.
- d) A polished slab of the laminated ironstone. The rhythmic laminae show convolute, slump and microfault structures, Safa Formation.
- e) Pseudonodule structure, introduced by the protrusion of muddy materials (1) into laminated ironstone (2), Safa Formation.
- f) Polished section of the rhythmic laminated ironstone of "abab" type, consisting of goethite laminae (1) and muddy laminae (2). Quartz grain (qz) exhibits loading structure in a goethite lamination, Safa Formation.
- g) Oxidized minute pyrite crystals and framboids, constituting the highly ferruginous laminae of the laminated ironstone, Safa Formation (Reflected Light).
- h) Polished section of the highly ferruginous laminae showing pseudomorphic goethite after siderite crystals (g), cemented by sparry calcite (cc), Safa Formation (Reflected Light).
- i) Polished section of the rhythmic ironstone of "abcabd" type, showing gradation from iron-free laminae (1) to goethite-rich laminae (2) with quartz silt Safa Formation.

and light, less ferruginous bands (Fig. 4c). These rhythmic ironstone bands exhibit well pronounced penecontemporaneous deformational structures, including : 1) scour and fill structures on the upper surfaces of the dark bands; 2) pseudo-nodular or ball and pillow-shaped masses of light sediment within highly ferruginous bands ; 3) wavy upper and lower surfaces which may have been produced by the action of turbulent currents ; and 4) fine cross lamination consisting of highly and less ferruginous laminae within certain layers. The rhythmic bands are commonly intersected by cross-cutting veinlets and fractures, filled by calcite .

Microscopically, the light bands contain terrigenous quartz sand (40%), carbonate bioclasts (35%) and subordinate carbonate ooids (5%) in a goethite and calcite cement. The iron content of these bands reaches 14 % . The dark bands consist essentially of terrigenous quartz silt (up to 30%) in a matrix of goethite and clay minerals (up to 70%). The iron content of these bands ranges between 31 to 39% Fe. The quartz grains are poorly sorted and subangular to subrounded . They are usually surrounded by secondary authigenic quartz growth and coated by a micrite envelope. Minute fresh and oxidized pyrite crystals are usually distributed in a circular alignment within the authigenic quartz overgrowth and micrite envelope. The bioclasts consist of skeletal debris of bryozoa, echinoid spines, pelecypods and gastropods, and may be filled or replaced by clusters of oxidized pyrite framboids. The margins of the skeletal debris are usually lined and corroded by spindle shaped crystals of siderite.

Laminated Ironstones

This ironstone type is widely distributed in the middle part of the Safa Formation, where it forms layers up to 50 cm thick. One bed, up to 20 cm thick, also is present in the upper part of the Kehailia Member. Each ironstone layer is formed of rhythmic laminae of variable iron content (up to 37% Fe) which range from 0.5 mm to 5 mm in thickness. Two types of rhythmic lamination are present . The first is an "ab-ab" rhythmic type which resulted from repetition of light yellow (poor in iron) and dark brown to green laminae (rich in iron). The laminae commonly exhibit convolute slumping and penecontemporaneous microfaulting (Fig. 4d). The second type consists of alternating "abc-abc" laminae of different shades of yellow, red and dark brown, respectively. Laminae are gradational into each other. The upper surfaces of the iron-rich dark laminae of the abc-abc type are commonly grooved. The dark laminae are also shredded into tiny discontinuous flat chips or curved polygons that are buried within the light laminae either randomly or as a semi-continuous horizon. Slump structure are also present in the abc-abc laminations. Both types of rhythmic laminations have been partially obliterated by the protrusion of muddy sediments from the overlying layers into the laminae, forming pseudonodule structure (Fig. 4e) .

The rhythmic laminae consist of clayey muddy sediment and quartz silt with a subordinate amount of bioclasts. The matrix includes oxidized pyrite and siderite in nodules.

rown laminae are enriched mainly in goethite after pyrite and siderite (Figs. 4g and 4h). In the abc-abc rhythmic type, the iron-free laminae pass gradually to dark goethite-rich laminae (Fig. 4i). Bioclasts are filled mostly with carbonates and iron oxides. Within the bioclasts, goethite pseudomorphs pyrite crystals, pyrite framboids and siderite or goethite masses devoid of any obvious internal structure.

Oolitic Ironstones

Oolitic ironstones are present in the Kehailia Member and throughout the Lower Cretaceous section of Gebel Manzour. They are generally friable, but become harder with increase in the calcareous component.

The friable variety of oolitic ironstone (up to 27% Fe) occurs mainly in the middle of the Gebel Manzour section, where it forms two beds alternating with clays and argillaceous limestones. The lower and upper beds are up to 5 cm and 1.35 m, respectively. They consist of loose, dark brown ooids associated with abundant quartz grains set in ferruginous clayey matrix. The ooids average 0.5 mm in diameter, and are rounded to well rounded and well sorted (Fig. 5a). Where flattened by compaction, they show sharp contacts with the matrix. The ooids consist mainly of massive goethite which usually contains a quartz nucleus (Fig. 5b). The quartz grains are subrounded to well rounded, poorly sorted and range between 0.1 to 0.5 mm in diameter. The clayey matrix consists of symmetrically alternating kaolinite rich dark brown to brownish yellow layers, up to 0.3 mm thick.

The more indurated oolitic ironstones are yellow to reddish brown and massive. They can be subdivided into quartz-rich and quartz-poor varieties. The former type is present in the upper part of the Gebel Manzour section, where it forms a stratiform layer about 35 cm thick and 20.44% Fe. The rock is composed mainly of ooids and quartz grains cemented by carbonate minerals (Fig. 5c). The quartz grains are poorly to moderately sorted, angular to subangular and range in size from 0.1 to 0.4 mm. The margins of the quartz grains are selectively replaced and partially coated by goethite laminae. Complete coating of quartz grains by goethite forms grains similar to true ooids. The ooids are subrounded, well to moderately sorted and moderately sorted and up to 0.5 mm in diameter. They have oval, flattened or rounded shapes and consist mainly of concentric goethite laminae or alternating goethite and chamosite laminae (Fig. 6). These laminae commonly surround ferruginous quartz grains, goethite pellets and carbonate particles (Fig. 5c). The carbonate cement consists mainly of sparite with or without rhombic zoned dolomite.

The quartz poor indurated oolitic ironstones (up to 19% Fe) are recorded only in the lower parts of the Kehailia Member and in the Gebel Manzour section. Beds are up to 1 m in thickness, and consist mainly of ooids, pellets and bioclasts with minor amounts of quartz grains and rock fragments. These constituents are embedded in micrite matrix associated with chlorite (Figs. 5d and 6), or cemented by sparry calcite (Fig. 5e). The pellets

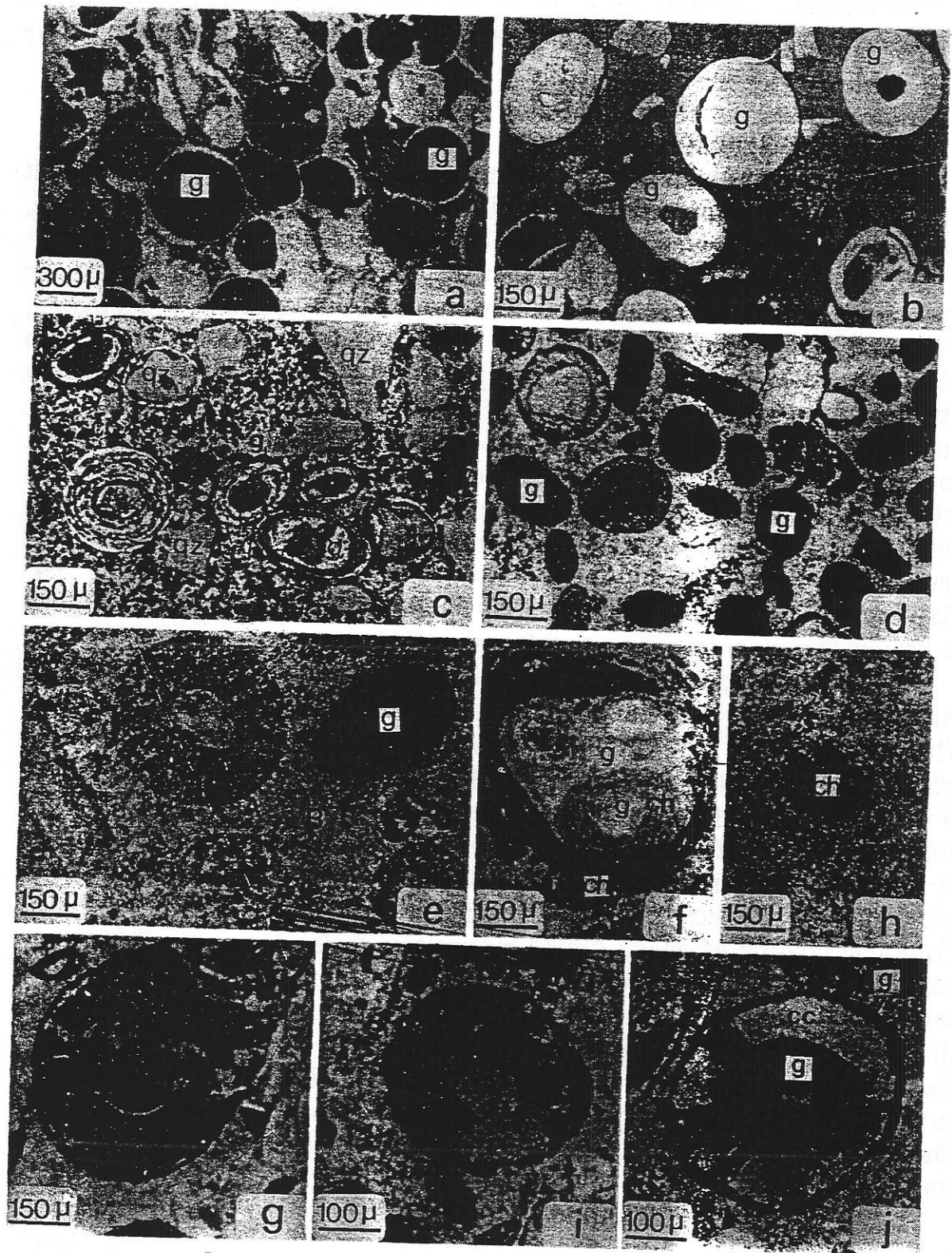


Fig. 5

- a) Thin section of the friable oolitic ironstone, consisting of goethite ooids (g), embedded in clayey matrix, Cretaceous oolitic ironstone of Gebel Manzour (// Nicols).
- b) Rounded goethite ooids (g) developed around quartz nuclei (qz), in friable oolitic ironstone. Gebel Manzour (Reflected Light).
- c) Iron ooids and quartz grains (qz) cemented by calcite (cc) in quartz rich indurated oolitic ironstone. The iron ooids consist of alternating layers of goethite (g) and chamosite (ch), Gebel Manzour (Reflected Light).
- d) Thin section of the quartz-poor indurated oolitic ironstone consisting of goethite (g) and micrite (m) ooids embedded in a micrite matrix, Gebel Manzour (// Nicols).
- e) Goethite (g) and carbonate (cc) ooids cemented by sparry calcite of fibrous (A) and blocky (B) forms, quartz-poor indurated oolitic ironstone, Gebel Manzour (// Nicols).
- f) Polished section of composite goethite ooids (g) surrounded by chamositic laminae (ch), in quartz-poor indurated oolitic ironstone, Kehailia Member.
- g) Well developed concentric chamosite ooid, in quartz-poor indurated oolitic ironstone, Kehailia Member (// Nicols).
- i) Granoblastic calcite ooid in quartz-poor indurated oolitic ironstone, Kehailia Member (+ Nicols).
- j) Rounded ooid of goethite (g) and calcite (cc) with an outer rim of goethite (g), in quartz-poor indurated oolitic ironstone, Kehailia member (+ Nicols).

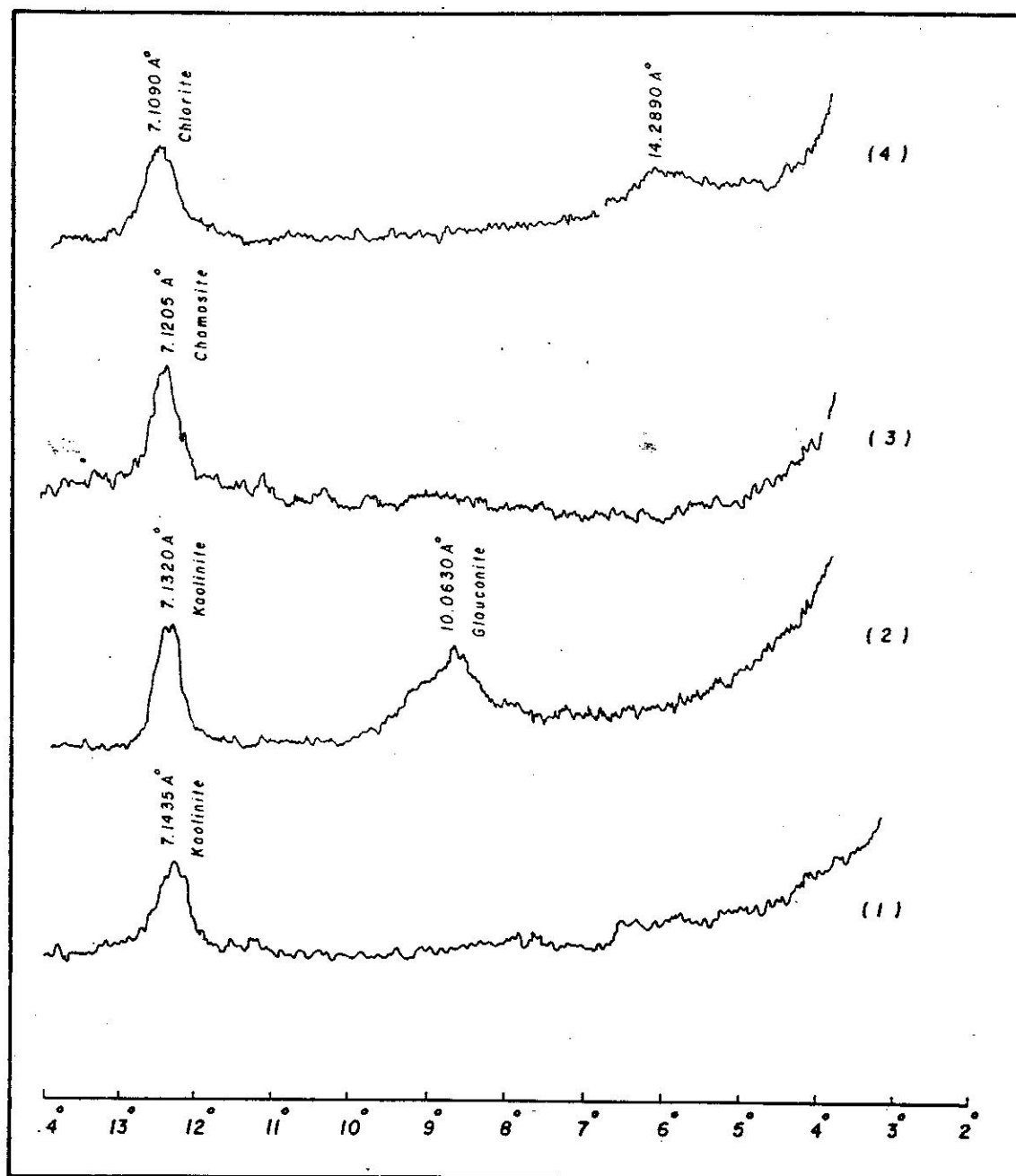


Fig. 6 : X-ray diffraction pattern (air dried)

- 1= Goethite massive ironstone, Shusha Formation.
- 2= Siderite bearing glauconitic massive ironstone, Lower Cretaceous sediments, Gebel Manzour.
- 3= Quartz-rich indurated oolitic ironstone, Lower Cretaceous sediments, Gebel Manzour.
- 4= Quartz-poor indurated oolitic ironstone, Kehailia Member.

are well rounded, well sorted and range in size from 0.02 to 0.2 mm. They are formed of iron oxides and lack internal structure. The skeletal debris are composed of echinoid spines and fragments of bryozoa, pelecypods and gastropods. Cavities within these fossils are partially or completely filled with massive goethite. The rock fragments comprise compound ooids and deformed ferruginous mudstone and siltstone (Fig. 5f). The ooids are well rounded, moderately sorted and range in size from 0.1 to 0.8 mm. They consist essentially of goethite and chamosite and are subspherical, flattened and ellipsoidal in shape. Nuclei and lamination are similar to the ooids of the quartz-rich oolitic ironstones. The goethite ooids are usually coated by thin carbonate laminae.

DIAGENETIC BEHAVIOUR OF THE IRON MINERALS IN THE IRONSTONES

The rhythmic banded, rhythmic laminated, concretionary banded, and massive ironstone types are dominated by pyrite, siderite and goethite with minor amounts of glauconite and hematite. By contrast, the oolitic ironstone types consist mainly of chamosite and goethite with rare pyrite and siderite.

Iron-Minerals in the Non-Oolitic Ironstone Types

Pyrite displays different morphologies which recently have been interpreted as depositional and early diagenetic forms (El Manawi, 1986 and El Aref and El Manawi, 1988). Minute scattered pyrite crystals or clusters are depositional products, whereas pyrite framboids in the form of individual grains or groups are early diagenetic. These two types of pyrite, with siderite, commonly occur within clay and silty matrix or fill fossil cavities. The framboids include the all ordered, unordered and infilled types of Love and Amstutz (1966). Marcasite and coarse-grained pyrite crystals (the late diagenetic pyrite forms of El Aref and El Manawi, 1988) have not been recognized in these ironstones. The pyrite grains are either fresh or completely altered to goethite and lepidocrocite.

Siderite is one of the main minerals of the ironstones, especially, the rhythmic banded and rhythmic laminated types and massive siderite-bearing glauconitic ironstone. The siderite generally forms rhombohedral or spindle-shaped crystals, usually altered to goethite and cemented by sparry calcite (Fig. 4h). It previously has been considered either as a primary precipitate (Fairbridge, 1967; Curtis and Spears, 1968) or diagenetic (Talbot, 1974 and Goldbery, 1980). The cementation of altered siderite crystals by the main sparite cement indicates that they were formed during early diagenesis, but after formation of framboidal pyrite.

The goethite is of both primary and secondary origin. Primary goethite is cryptocrystalline and forms nodules, earthy masses and concentric colloform layers. The earthy goethite forms the main constituents of the massive and clayey ironstones. Concentric colloform layers of goethite together with hematite are the main constituents of the banded concretionary

Some primary goethite may also invade the margins of quartz

grains and fossil debris. The secondary goethite was formed during the oxidation of the depositional pyrite (minute crystals) and early diagenetic pyrite framboids and siderite which form the main constituents of the rhythmic banded and rhythmic laminated ironstones.

Iron Minerals of the Oolitic Ironstone Types

The ooids of these ironstones include chamosite, chamosite-goethite, goethite, goethite-micrite, and micrite varieties. The lattermost two types occur in subordinate amounts. The ooids are either embedded in clayey and micritic matrix or cemented by calcite.

The chamosite ooids have a well developed concentric structure, and vary in colour from pale to dark green with yellowish and brownish tints (Fig. 5g). The ooids are partially or completely oxidized to goethite, some of these are coated by thin calcite laminae. The chamositic ooids are gradually replaced by calcite, and in places appear as ghosts in a calcareous matrix (Fig. 5h); all gradations between chamosite ooids and calcite ooids are present. Replacement must have been from the outer surfaces of the chamosite ooids towards the center, leading to gradual obliteration of the original concentric structure. The ultimate stage of chamosite replacement formed a coarse granoblastic texture (Fig. 5i). The external ooidal shape is preserved where it contains faint inclusions marking the original concentric texture (with or without relicts of chamosite). Residual concentric laminae within the replaced ooids are outlined by oxidized ferruginous material which may indicate partial oxidation of original chamosite during the replacement process.

The chamosite-goethite ooids are formed either of a chamosite core and concentric goethite outer zone, or of alternating chamosite and goethite laminae (Fig. 5c). Oxidation processes may have altered some of the chamosite laminae to goethite, as suggested by the presence of chamosite relicts.

The goethite ooids form individual (superficial or normal) and composite types. The superficial ooids are formed by deposition of a goethitic crust around detrital quartz grains; the absence of a such coating at grain contacts indicates a diagenetic origin (Tucker, 1981). Most normal goethite ooids have more than one concentric or eccentric lamination, although, some grains have no internal fabric. The ooids are commonly twisted and fractured forming a spastolithic texture; fractures are filled with clear calcite. Spastoliths are thought to document the effect of early-to late-phase diagenetic compaction (Adeleye, 1973). The goethite ooids are characterized by bumpy outer surfaces which may result from replacement by the interstitial matrix (Carozzi, 1960).

The goethite-micrite ooids are formed either of goethite coated by thin micritized laminae, or of a micrite core coated by goethitic laminae. Recrystallization (neomorphism) of the micrite laminae led to growth of radial calcite on the surfaces of the goethitic laminae (Fig. 5i).

The micrite ooids consist of more than one concentric laminae around a quartz nucleus. Some of these laminae have a radial fabric. The micrite laminae are commonly recrystallized into coarse granoblastic calcite which contains faint inclusions marking the original concentric texture.

The cement of these ooids includes two distinct generations. The early generation is represented by a thin fringe of fibrous calcite developed normal to the outer surfaces of the ooids. The late cement consists of clear sparry calcite which fills remaining pore spaces (Fig. 5e). These cements are similar to the early and late diagenetic cements of Füchtbauer (1974).

DISCUSSIONS AND CONCLUSIONS

The Egyptian ironstones of El Maghara area are intimately associated with a transitional environment of alternating paralic and shallow marine platform sediments, comprising marginal facies of the epicontinental Tethyan sea at lower part of the northern Latitudes, during the Jurassic and Early Cretaceous. These sediments have been deposited in tectonically active basin situated along the northern unstable shelf of the Afro-Arabian craton, bounded to the east and south by the equivalent continental and lateritic sediments and to the north by active hinge-line and the Tethyan sea. The paleogeographic situation of the studied Jurassic ironstones, in relation with the evolution of the Tethyan realm correlated closely with that of the well known Jurassic ironstones of the world e.g., the Minette ores of Luxemburg and Lorraine (Teyssen, 1984), the Westbury and Wiltshire ironstones of South England (Talbot, 1974), Harz and Rheinische Schiefergebirge, Northwest Germany (Böttke et al., 1969), which developed along the margins of epicontinental seas of the Tethys (Van Houten, 1985) and also are associated with coal bearing sediments (Hallam, 1975 and 1984). The same paleogeographical and paleoenvironmental situation appears to be extended until the Aptian-Albian time, where the Lower Cretaceous ironstones of the study area developed, which can be correlated with the Aptian ironstones of Gdeidet Yabous and Naba Barada, Zebdani, Syria (El Dallal, 1975). Towards the southern part of Egypt, the Late Cretaceous (Turonian - Santonian) oolitic ironstones at the vicinity of Aswan down to the western shores of Lake Nasser are related to similar paleoenvironmental conditions, as they seem to be deposited in shallow marine to restricted paralic lagoonal environments with corresponding kaolinitic and bauxitic laterites in the hinterlands (Said et al., 1976; Bhattacharyya, 1980; Van Houten and Bhattacharyya, 1982; Klitzsch, 1986 and German et al., 1987). This may reflect creation of such environments and basins suitable for ironstone formation at lower latitudes during the Late Cretaceous, as a result of the southward migration of the Tethyan margin, with contemporaneous development of laterites on the adjacent lands.

The studied ironstones are confined within deltaic, shallow shelf lagoonal intertidal and shoal sediments, and include concretionary banded, massive, clayey, rhythmic banded, rhythmic laminated and oolitic types.

The concretionary banded ironstone interrupts the coarsening upward successions of deltaic sediments. It forms hard cap covering highly ferruginous and mottled substrata and can be correlated with the upper indurated horizon of typical ferricrete (paleosol) profile (Faniran and Jeje, 1983). The development of the concretions can be attributed to the accumulation and enrichment of iron during the processes of denudation, assisted by the capillary rise of sesquioxide rich soil solution under fluctuating ground water. The composition and concentric fabric of the concretions indicate that rhythmic chemical precipitation alternated with mechanical sediment incorporation, with changes, in the degree of hydration of the iron minerals during the diagenesis.

The rhythmic banded, rhythmic laminated and massive ironstones are closely associated with or even form the fine-grained intervals of the cyclic fluvial facies, suggesting that the iron has been derived from the hinterlands, and was carried into the deltaic basin, mainly as suspension or soluble forms (ferrous state or complex organic form), where deposition and diagenesis took place. Pyrite crystals and framboids accumulated in beds or laminae in the depositional and early burial stages under anaerobic conditions at and below the sediment-water interface. Sulphide deposition was followed by the crystallization of siderite. The change during early diagenesis from pyrite to siderite indicates a decrease in the availability of sulfur (Curtis and Spears, 1968). The sulphide- and carbonate-bearing laminae and bands appear to have been subsequently oxidized, leading to the formation of pseudomorphic goethite after pyrite and siderite. Cementation of the oxidized iron minerals by sparry calcite suggests that oxidation conditions were maintained during later diagenesis. The establishment of oxidizing conditions soon after the formation of pyrite framboids and siderite may explain the absence of marcasite and coarse-grained pyrite (the late diagenetic iron sulphide forms of El Aref and El Manawi, 1988). These reduction - oxidation changes correspond to the redoxmorphic diagenetic stage of Dapples (1967). The synsedimentary deformational features of the highly ferruginous bands and laminae suggest that oxidizing conditions were established near the surface.

The oolitic ironstones form individual beds encountered within sediments of shallow shelf lagoonal, mixed intertidal to shoal environments. These beds have sharp contacts with the overlying and underlying iron-poor sediments. The goethite ooids are suggested to be formed in agitated water as true ooids under oxidizing condition, where the clay winnowed out (Schellmann, 1969, ; James and Van Houten, 1979 ; Van Houten and Karasek, 1981 and Maynard, 1983). They appear to have been washed from the site of formation and deposited in less agitated shallow environment rich in calcareous mud. the presence of calcareous micrite laminae within iron ooids and the association of calcareous and iron ooids in the cemented oolitic ironstones indicate that these ooids were accumulated in very shallow agitated waters with variable proportions of detrital influx, and cemented by sparry calcite, once they come to rest for an adequate period. The chamosite ooids must have formed under reducing conditions (Huber and Garrels, 1953 ;

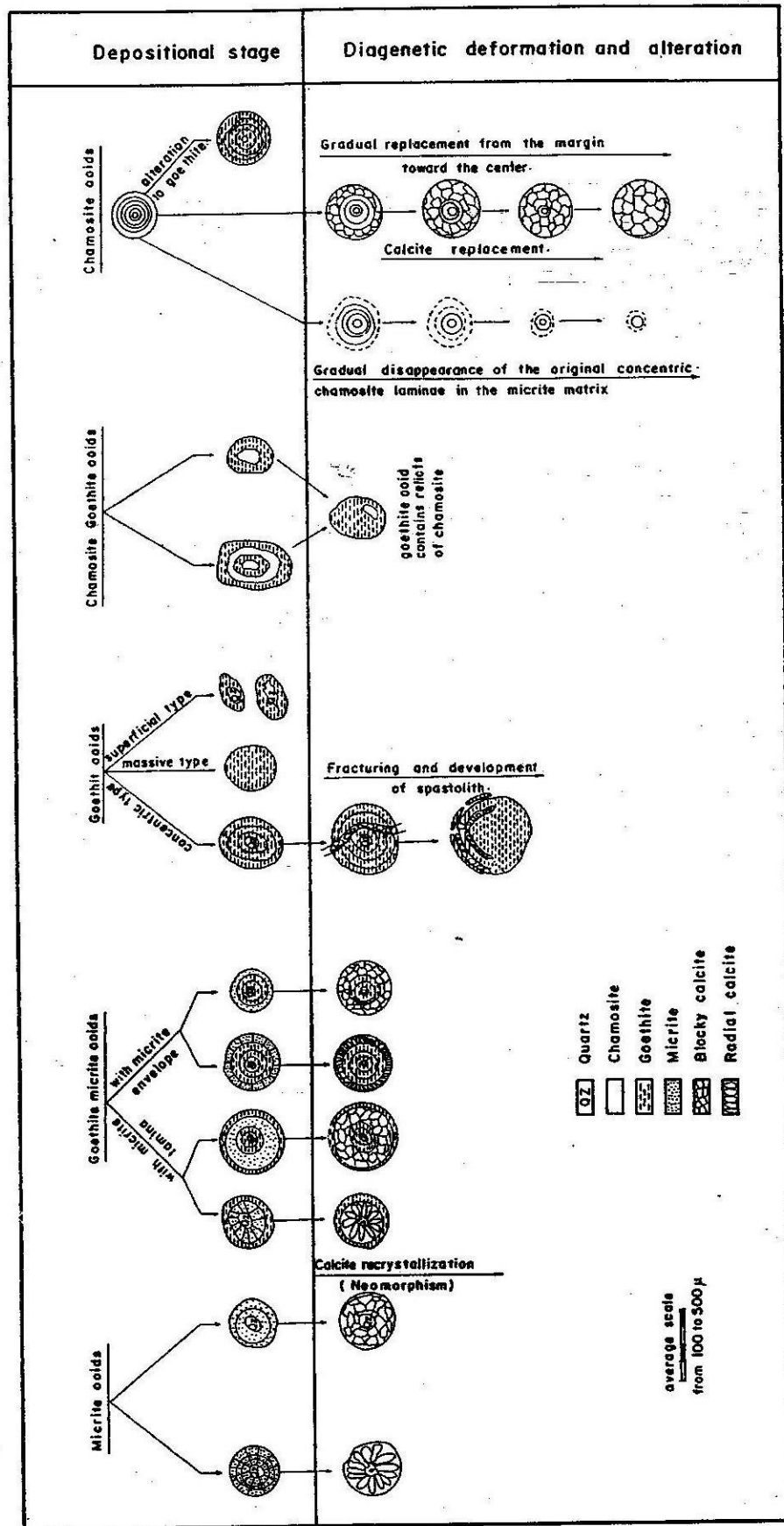


Fig.7 : Depositional and diagenetic textural fabrics of the ooids of the different oolitic ironstone types.

Chilingar, 1956 ; Hallam, 1966 ; Porrenga, 1967 and Curtis and Spears, 1968). The concentric alternating goethite-chamosite laminae within the ooids suggest oscillating oxidizing and reducing conditions at the sea floor (Alling, 1947 ; Taylor , 1949 and Brookfield, 1971). The morphology and composition of the primary calcareous and iron ooids were subsequently affected by the following diagenetic modifications (Fig. 7) : 1) final oxidation of chamosite to goethite, leading to obliteration of the concentric fabrics of the ooids ; 2) formation of superficial goethite ooids ; 3) replacement of chamosite by calcite ; 4) recrystallization of the micrite envelopes and the internal micrite laminae into sparry calcite; 5) fragmentation of the goethite ooids and formation of spastoliths ; and 6) filling of the fractures within the ooids by sparry calcite. The idea that the ooids of oolitic ironstones are the result of diagenetic replacement of pre-existing aragonite ooids by downward-percolating meteoric waters (Kimberley , 1979, 1980) cannot be accepted for the studied oolitic ironstones on the bases of the following : 1) the composition and internal fabrics of the ooids and their diagenetic modifications and cementation by late calcite ; 2) the sharp contact between these oolitic ironstones and the overlying and underlying shale, and 3) the lack of evidences indicating leaching of iron from the sediments immediately above the ironstones or gradation from oolitic limestone to oolitic ironstone. The early formation of the ooids and the replacement of chamosite by calcite have been cited as evidences against the replacement model (Bradshaw et al, 1980 ; Hallam and Bradshaw, 1979 ; and James and Van Houten, 1979) .

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